

Summary

Grade Level: 10 - 12

Teaching Time: Two 40 minute periods

Activities:

- **Discuss how carbonate saturation and supersaturation affect marine life that requires calcium carbonate to form their shells and frameworks.**
 - **Use real data to understand how atmospheric CO₂ levels affect the health of marine calcifiers.**
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Objectives

- Students will examine the relationship between aragonite saturation levels and the health of marine calcifiers.
- Students will use online data to support or disprove a simple hypothesis about increased atmospheric CO₂ and the health of marine calcifiers, such as coral reefs.

Background

The calcium carbonate (CaCO₃) in coral reefs and in the shells of other marine calcifiers comes in two different mineral forms: calcite and aragonite. The seawater at or near the ocean's surface in the tropics is supersaturated with the ions necessary to form these carbonate minerals. Ocean acidification reduces carbonate ion saturation, making it harder for marine organisms to produce the CaCO₃ that they use to form their shells and frameworks.

Studies of reef-building corals show a decline in the coral polyps ability to create CaCO₃ as aragonite saturation levels decrease. Even though the water continues to be supersaturated with the ions necessary to form aragonite, lower ion concentrations have a negative effect on the health of the coral organism. As aragonite saturation levels fall, the organism must divert energy from other important life functions to elevate ion concentrations within the immediate area of the coral tissue to allow it to continue creating its aragonite framework. If the coral polyps cannot produce CaCO₃ quickly enough, the coral reef as a whole will stop growing and begin to erode.

Corals mostly use aragonite to build reefs. Sea butterflies — pteropods — also produce shells made of aragonite, as do some mollusks. Two types of phytoplankton — coccolithophores and foraminifera — use

calcite, not aragonite, to form their shells. Increases in atmospheric CO₂ threaten the future of all these marine organisms as ocean acidity increases and carbonate ion concentrations decrease over time. For coral reefs, the effects of falling aragonite saturation levels include slower coral growth rates and decreased skeletal density.

Vocabulary

aragonite – a mineral form of calcium carbonate CaCO₃ that is often used by marine life to form skeletons and shells.

marine calcifier – an organism that lives in the ocean and is able to form or accrete its own shell or framework using calcium and carbonate ions found in seawater.

saturation state – the degree to which a solution is saturated with a solute. A solution with saturation of 1 Ω is saturated. Solutions with Ω greater than 1 are oversaturated (called supersaturated). Solutions with Ω less than 1 are undersaturated.

Preparation

It is recommended that you do not show students examples of aragonite saturation maps and graphs before they begin this activity. A goal of this investigation is to encourage students to examine unknown data, and use skills and techniques they learned earlier to read and interpret that data.

You should still familiarize yourself with representations of this new data set, however, by following the instructions below.

1. Visit www.dataintheclassroom.org and click on the Ocean Acidification module link.
2. To access the data area for the Ocean Acidification module, select the “Get Data” link at the bottom of the left menu.
3. Select “Saturation state (aragonite)” in the “Which parameter?” pulldown.
4. Next select “Map” on the menu labeled “Which view?”
5. Specify the date by changing the date input to “August 2010.”
6. Select “Image” on the menu labeled “Select an output format.”
7. Finally, click the “Get Data” button. A new browser window will open that contains the aragonite saturation map image you requested. When you have finished viewing the graph image, you may close that browser window.
8. Next create a time-series graph. The first graph will show changes

in aragonite saturation over time for a point located in the middle of the default study area. You do not need to change the parameter or output format selections.

9. First, change from “Map” to “Time series graph” on the menu labeled “Which view?”
10. Change the first date input to “January 1988” and the second date input to “August 2010.”
11. Click the “Get Data” button. A new browser window will open that contains the time-series graph image you requested. This graph shows changes in aragonite saturation (Ω) from 1988 to 2010 for a location at the center of default geographic area. When you have finished viewing the graph image, you may close that browser window.
12. Repeat the procedure to look at different dates or to generate different time-series graphs.

In this activity, students will be asked to create data tables and simple graphs using aragonite saturation data they find online at www.dataintheclassroom.org. Students may find it helpful to use spreadsheet software, such as Microsoft Excel or OpenOffice Calc, to work with and interpret the data.

Materials

- Copies of Student Master, Research Project:
Exploring Aragonite Saturation Data
- Copies of Student Master, Data Log Sheet
- Student access to computers with Internet connection
- Spreadsheet software (optional)
- Graph paper
- Ruler

Procedure

This activity challenges students to think like scientists by designing a scientific investigation in which data collection and analysis are important parts of the process. Students are asked to use the scientific method, using real data to solve a problem.

1. Discuss the scientific method with your students. They will almost certainly have had exposure to the scientific method in their science classes in the past. However, they may not be familiar with the term “research question.” A research question is

Video



View this demonstration at
www.dataintheclassroom.org

the question that the research sets out to answer. A hypothesis is one possible answer to that research question. It is the hypothesis that the researcher tests and evaluates as a possible answer to the research question.

2. Students should have as prior knowledge that adding CO_2 to water creates carbonic acid and that increased CO_2 levels in Earth's atmosphere are causing decreased alkalinity in Earth's oceans. The next important point is to connect ocean acidification with its effects on marine life. Show your students a video, *Impact of Acidification on Organisms*, in which Dr. Jane Luchenco demonstrates how lower pH affects marine life, including pteropods.
3. Near-surface ocean water is supersaturated with ions that marine organisms need to form their calcium carbonate (calcite and aragonite) shells or skeletons. You may want to review saturated solutions and the concept of supersaturation with your class at this time.
4. The saturation levels of the ions necessary for marine calcifiers to form shells and skeletons are an important measure of how marine life is reacting to ocean acidification. Show your students the graph on the Teacher Master. Call your students' attention to the following features of the graph:
 - The main x-axis is aragonite saturation measured in Ω . An aragonite Ω value greater than 1 means the seawater is supersaturated with ions needed to precipitate aragonite. An aragonite Ω value less than 1 means the seawater is undersaturated with those ions.
 - The y-axis shows calcification rate. This is a measure of how efficiently a marine calcifier is able to form its shell or skeleton by precipitating aragonite. The unit on this axis is percent calcification efficiency based on 100% efficiency in the year 1880, which was the beginning of the Industrial Era

Take Note

Supersaturation & Precipitates

Some of your students may ask: “In the lab, I see precipitation occur in supersaturated solutions. Why doesn’t calcium carbonate just precipitate out of the tropical sea water until the aragonite saturation reaches 1?” One reason more precipitation of CaCO_3 does not occur is because there are materials in the sea water (phosphate ions, magnesium ions, and organics) that get in the way. A seed crystal of CaCO_3 cannot get large enough to precipitate out of solution because its surface is effectively cut off from the additional calcium and carbonate ions it needs to grow.

when humans began pumping excessive amounts of CO_2 into Earth’s atmosphere. Thus, 80% along the y-axis means that an organism is only 80% as efficient at precipitating aragonite at that time as it was in 1880 when atmospheric CO_2 levels were much lower.

- The second x-axis is used to relate years to aragonite saturation and calcification data. Using this axis, students should see that at 1880, calcification rate was at 100% and aragonite saturation was over 4.5 Ω .
- Based on numerous experimental studies of marine calcifiers in varying aragonite saturation levels, the white line shows how the organism’s ability to calcify is affected by changes in aragonite saturation levels. Students should see that, as aragonite saturation levels decrease, the marine calcifier’s ability to form its shell or skeleton by precipitating aragonite also decreases. As aragonite saturation decreases, so does calcification rate.
- The amount by which the decrease in calcification rate affects the marine calcifier’s ability to form and maintain its shell or skeleton is indicated by the color areas. Levels above 4.0 Ω are optimal for aragonite precipitation. Levels of 3.5 to 4.0 Ω are considered only adequate for coral growth. Aragonite saturation levels of 3.0 to 3.5 are marginal or low. Below 3.0 Ω , conditions are extremely marginal, even critical. It is highly possible that corals would no longer exist as we know them at aragonite saturation levels of 3.0 Ω or lower.

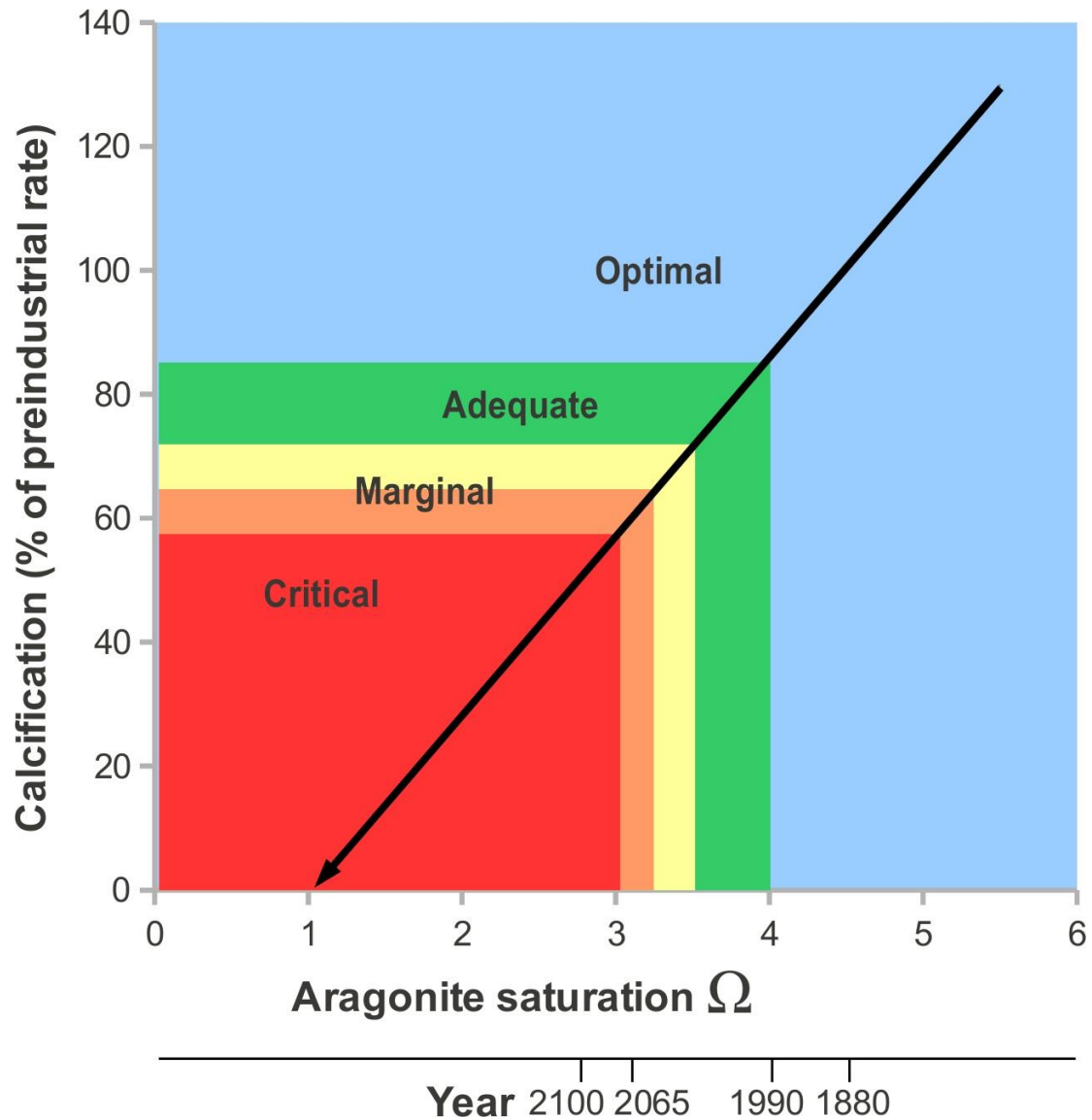
Focus student attention on the graph by asking the following questions: *Do marine calcifiers require water to be supersaturated with the ions necessary to form calcium carbonate? In what year did conditions change from Optimal to Adequate for corals?*

5. If you have additional time, you may choose to revisit the

carbonate simulation from Level 3 at this time. Visit www.dataintheclassroom.org and click on the Ocean Acidification module link. Follow the link to “Carbonate Simulation.” Run the IPCC scenario and have students examine the aragonite saturation graph line relative to calcification. *How many years does it take for aragonite saturation to reach the 3.5 Ω marginal level? What is the calcification rate at that level?*

6. Assign students to work in teams of two. Give each team a copy of the Student Master, Research Project: Exploring Aragonite Saturation Data and the Student Master, Data Log Sheet.
7. Offer students a hint that they may want to look at historical data in order to predict the future. Online data for dissolved CO₂ can be used as a stand-in for atmospheric CO₂. If they have not already, make sure students understand that aragonite saturation is one of the data parameters available online in the Ocean Acidification module’s “Get Data” area.
8. Students will need to access the Internet to generate and save data maps and graphs. Depending on the setting, this can be done in a computer lab or assigned as homework, assuming your students have access to the Internet at home, at a library, or in a computer center.
9. If students are using spreadsheet software, they may need guidance on setting up their spreadsheet and graphs. Show students that they can get raw data online to use in their spreadsheet by choosing “Data file for spreadsheet” under “Select an output format.”
10. Have students use the scientific method to carry out their investigation on the harmful effects of atmospheric CO₂ on marine calcifiers. When they have finished, have teams present their findings to the class.

Carbonate Simulation



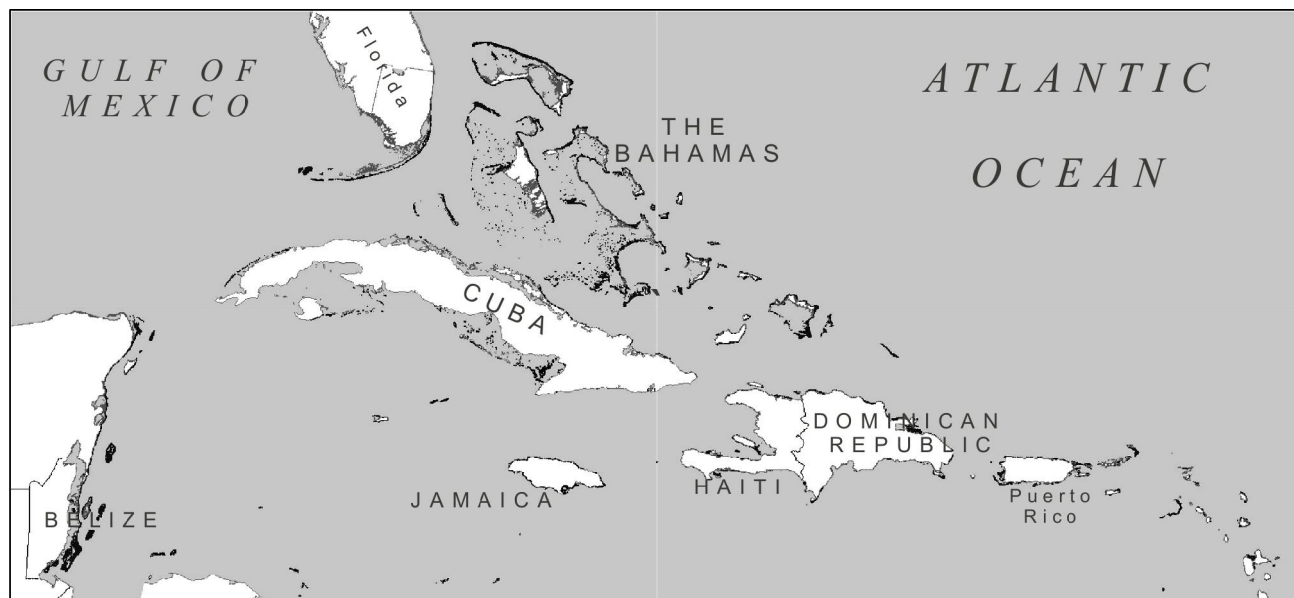
Sources:

- Langdon C, Atkinson MJ (2005) Effect of elevated pCO₂ on photosynthesis and calcification of corals and interactions with seasonal change in temperature/irradiance and nutrient enrichment. *J Geophys Res* 110, C09S07.
- J. M. Guinotte, R. W. Buddemeier, J. A. Kleypas, Future coral reef habitat marginality: temporal and spatial effects of climate change in the Pacific basin. *Coral Reefs* (2003) 22: 551–558

Student Master

Research Project: Exploring Aragonite Saturation Data

You have joined a team of scientists who are studying the effects of atmospheric CO₂ on coral reefs in the Caribbean Sea. Coral reefs grow near the coasts of islands in the Caribbean (see map below), where the waters are warm, shallow, and rich in the dissolved materials coral organisms need to build the coral reefs.



Map provided by ReefBase. Coral reef location data provided by UNEP-WCMC. <http://www.reefbase.org/>

As aragonite saturation levels decrease, it becomes harder for marine calcifiers to precipitate the aragonite for their skeletons. Studies have shown that coral reef organisms are best able to build reefs when aragonite saturation in surface waters is greater than 4.0 Ω . Levels of 3.5 to 4.0 Ω are considered only adequate for coral growth. Aragonite saturation levels of 3.0 to 3.5 are marginal or low, with 3.3 Ω often called the critical threshold for reef growth. Major coral reef systems are not found in water with aragonite saturation below the critical 3.0 Ω level. At these levels, even though the water is still supersaturated in calcium and bicarbonate ions, the organisms cannot divert enough energy from their other life processes to precipitate adequate amounts of aragonite to form and maintain their framework.

Your task is to determine whether increased levels of CO₂ in Earth's atmosphere are affecting aragonite saturation levels in near-surface waters of the ocean, and, if so, at what point will decreasing aragonite saturation levels affect coral reefs in the Caribbean. First, you will prepare a research plan that describes what data you will need to examine and why, what investigation methods you will use, and how you will collect data. Once your plan is accepted, you will carry out your data collection, analyze your data, and report your findings to the team.

Planning your project:

1. Form a hypothesis to answer the research question below.

Research Question: Are increased levels of CO₂ in Earth's atmosphere affecting ocean chemistry in ways that are increasingly unfavorable for marine life, such as corals and pteropods, which create shells and skeletons from aragonite?

Hypothesis: As the concentration of CO₂ in Earth's atmosphere increases, aragonite saturation levels in the ocean will continue to fall, eventually reaching a level at which marine calcifiers, such as coral reefs, can no longer grow and maintain their shells or skeletons.

2. Design a plan to test your hypothesis and answer the research question.

What do you need?

- a) More information: Do you need more information about aragonite, atmospheric CO₂, the ocean's carbonate buffering system, or marine calcifiers?
- b) Specific data: When you go online to collect data, which of the following maps and graphs will you generate?
- c) Aragonite saturation maps
- d) Aragonite saturation time series graphs
- e) Dissolved CO₂ (pCO_{2sw}) maps
- f) Dissolved CO₂ (pCO_{2sw}) time series graphs
- g) Other?

3. Go online and get the data.

- a) Visit www.dataintheclassroom.org, and find the Ocean Acidification module.
- b) Follow the link to "Get Data."
- c) Using the form, select the data and parameters you wish to look at.
- d) Click the "Get Data" button.

4. **Use the Data Log Sheet to keep a record of the data you select and/or save so you can refer to it later.**

Remember to save or print maps and graphs so that they can be used later for data analysis and then shown to your classmates when you present your findings.

5. **Analyze the data by answering the following questions:**

- a) Describe the pattern of change in dissolved CO₂ (pCO_{2sw}) in the study area over time. How does dissolved CO₂ relate to levels of atmospheric CO₂?
- b) Describe the pattern of change in aragonite concentration (Ω) in the study area over time.
- c) If you assume a steady rate of aragonite saturation decrease over time, when will coral reefs reach the critical 3.3 Ω level? (Hint: You can get raw data online by going online to create a time-series graph and selecting “Data file for spreadsheet” under “Select an output format.” Then you can graph the aragonite saturation data by hand using graph paper or use a spreadsheet.)
- d) Check your work using the carbonate buffering simulation. Assume a change in atmospheric CO₂ of +2ppm/year and increased sea-surface temperature of 1.3 °C over 100 years.

6. **Draw conclusions.**

Write down what you learned from your investigation. Use your data to help you decide whether your hypothesis is supported. If your hypothesis is not supported, think about other data you might need to collect.

Student Master

Data Log Sheet

As you use the online data access form to select data about reef-growing conditions in the Caribbean study area, keep a record of the parameters you select on this data log sheet. Your data log will help you remember and keep track of the data you have looked at. Consider whether each new piece of data helps support or disprove your hypothesis.

	Data set	Map or graph?	Region	Date(s)	Notes
1	Aragonite	Map	15 to 20 N. latitude 90 to 60 W. longitude	March 2010	Saved to disk as "Arag01.gif"